ARM TR-019

Micropulse Lidar (MPL) Handbook

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Contents

1. General Overview

The Micropulse Lidar (MPL) is a ground-based optical remote sensing system designed primarily to determine the altitude of clouds overhead. The physical principle is the same as for radar. Pulses of energy are transmitted into the atmosphere; the energy scattered back to the transceiver is collected and measured as a time-resolved signal. From the time delay between each outgoing transmitted pulse and the backscattered signal, the distance to the scatterer is infered. Besides real-time detection of clouds, post-processing of the lidar return can also characterize the extent and properties of aerosol or other particle-laden regions.

2. Contacts

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3. Deployment Locations and History

SGP-C1, Lamont: The MPL at SGP is currently operating within specifications.

NSA-C1, Barrow: A prototype MPL having polarization sensitivity has been operating at Barrow since November 2003. As this capability is still under development, only the standard MPL product is being operationally produced from this prototype system.

TWP-C1, Manus: The MPL at Manus is currently operating within specifications.

TWP-C2, Nauru: The MPL at Nauru is currently operating **below** specifications. While still capable of detecting high cirrus, the daytime sensitivity is much reduced. This system is anticipated to be replaced in May 2004.

TWP-C3, Darwin: The MPL at Darwin has been returned to NASA GSFC for renovation with return expected in early June 2004. This system is anticipated to be replaced in Darwin in July 2004.

In response to unacceptable down-time and lengthy repairs, ARM is purchasing additional MPL systems as spares. An additional three spares have been contracted with the first of these to be received in April 2004. In addition, a new MPL will be procured for the ARM Mobile Facility.

4. Near-Real-Time Data Plots

See SGP Quick Looks.

5. Data Description and Examples

See MPL Quick looks from NASA-Goddard Space Flight center.

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

The Micropulse Lidar (MPL) has one measurement channel that records backscatter signals up to 20+ kilometers. The primary quantity from this signal is the lowest detected cloud base in meters.

Additional quantities possible through post-processing of the raw signal return include a relative backscatter profile at 523 nm. From the relative backscatter profile, other data products are possible including multiple cloud decks, cloud and layer boundaries, as well as aerosol extinction and backscatter profiles.

5.1.1.1 Definition of Uncertainty

The uncertainties in reported cloud base height have several sources. There is an inherent calibration uncertainty of the timing electronics of about 2%. This translates directly into an uncertainty of +/- 2% for all reported distances.

Also, the measured lidar profiles are collected in discrete "range bins" with finite width. Reported cloud heights are centered within the range bin, so cloud base heights will have an uncertainty of +/- 1/2 the range resolution. Early MPL systems deployed at SGP and TWP C1 (Manus) had a range resolution of 300 meters. ARM MPL systems are currently operated with 30 meter resolution including all MPL data ever collected from NSA, TWP C2 (Nauru), and TWP C3 (Darwin).

There are also several uncertainties that are more difficult to quantify. The MPL is an eyesafe lidar, and as such transmits a very low power laser beam, typically less than ~25 mW at 523 nm. Thus, it is subject to signal to noise limitations in conjunction with solar background noise. Moreover, the laser beam is attenuated or extinguished as it passes through the atmosphere. These two effects combine to make detection of high thin clouds more difficult during the day. Furthermore, over time laser systems degrade and produce less powerful pulses, so the sensitivity of the MPL will depend on the health of the laser system in the MPL. In addition to these measurement limitations, there are other uncertainties that are difficult to quantify. Exactly "what is a cloud" is difficult to define. Algorithm differences can yield biases in reported cloud base height. More significantly, one algorithm may identify a particular atmospheric structure as being “cloud” while another algorith may not, so algorithm sensitivity is also a difficult uncertainty to quantify.

5.1.2 Secondary/Underlying Variables

This section is not applicable to this instrument.

5.1.3 Diagnostic Variables

This section is not applicable to this instrument.

5.1.4 Data Quality Flags

Besides actual cloud-base heights, there are two sentinel values present in the data.

A cloud-base height = 60 kilometers is reported for a “blocked beam” condition. Literally, this condition means that insufficient backscatter has been detected at even near-range bins. This situation can arise from heavy fog or can be caused by water, ice, or debris accumulating on the view port window.

A cloud-base height = 0 is reported when the sky overhead is determined to be cloud-free.

5.1.5 Dimension Variables

This section is not applicable to this instrument.

5.2 Annotated Examples

This section is not applicable to this instrument.

5.3 User Notes and Known Problems

This section is not applicable to this instrument.

5.4 Frequently Asked Questions

What MPL datastream should I use for clouds?

Use ARSCL if it is available. If not, then use MPLnor. If neither, use the a1-level file.

What MPL datastream should I use for aerosol products?

ARM MPL aerosol retrievals are currently in development but are not operationally available. For limited periods, aerosol products from the ARM MPL at SGP is available from NASA’s MPLnet. For qualitative indications of aerosol, the normalized backscatter profiles from MPLnor are excellent indicators of aerosol layers and relative abundance. Use of a1-level MPL datastreams for aerosol detection is not advised.

What is the lowest cloud the MPL can detect?

Early MPL systems had relatively coarse range resolution of 300 meters. Also, these systems had high levels of detector "afterpulse", a long-lived residual of the transmitted laser pulse evident in the range-resolved profile, but not actually emanating from the atmosphere. Additionally, all MPL systems require correction of near-range signal with the magnitude of the correction increasing inversely with distance. These three elements combined to limit initial MPL cloud detection to about 300 meters. Improvements in all three areas now offer the potential of reducing this to perhaps 60-90 bins, but current algorithms still use the old lower limits.

6. Data Quality

6.1 Data Quality Health and Status

The following links go to current data quality health and status results.

- DQ HandS (Data Quality Health and Status)
- NCVweb for interactive data plotting using.

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

QC frequency: Monthly basis

QC delay: Next week

QC type: Graphical plots

Inputs: Raw data

Outputs: Raw cloud base height (cbh) estimates compared with VCeil and MPL cbh estimates; processed backscatter profiles

Reference: Routine data quality monitoring of the MPL at the SGP consists mainly of cross comparison of raw MPL cloud base height (cbh) estimates with those from the VCeil.

6.3 Data Assessments by Site Scientist/Data Quality Office

All DQ Office and most Site Scientist techniques for checking have been incorporated within DQ HandS and can be viewed there.

6.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the ARM Program are met through the analysis and processing of existing data products into "value-added" products or VAPs. Despite extensive instrumentation deployed at the ARM CART sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the program. Conversely, ARM produces some VAPs not in order to fill unmet measurement needs, but instead to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces "best estimate" VAPs. A special class of VAP called a Quality Measurement Experiment (QME) does not output geophysical parameters of scientific interest. Rather, a QME adds value to the input datastreams by providing for continuous assessment of the quality of the input data based on internal consistency checks, comparisons between independent similar measurements, or comparisons between measurement with modeled results, and so forth. For more information see VAPs and QMEs.

Two VAPS currently use the raw MPL datastream. Whenever possible, the following value-added products should be used in preference to the raw or a1-level MPL datastream.

- **MPLnor**: "MPLnor" stands for *MPL normalized*. It produces "normalized" backscatter profiles (in arbitrary units) with all known instrument artifacts removed. To improve signal to noise, MPLnor applies further temporal and spatial averaging. It also reports up to three layers of clouds along with cloud base and cloud top when possible. Both a "sensitive" and "robust" cloud mask are provided where the "robust" cloud mask is simply the "sensitive" mask with some filters applied to remove false positives.

- **ARSCL**: "ARSCL" stands for *Active Remotely-Sensed Cloud Locations*. It represents a composite product combining measurements from ceilometers, lidar, and radar. Lidar and radar measurements are complementary in that lidar are more sensitive to smaller particles often found in cirrus or low water vapor clouds. However, radar is able to penetrate multiple cloud decks that are impossible for lidar to penetrate. Thus, this composite product provides the best of both instruments and is currently ARM's last word on cloud detection.

In addition, several other VAPs involving MPL measurements are under development including:

- Thin-cloud optical depth retrieval
- Aerosol properties retrievals
- Depolarization ratios
- Slant-path optical depth retrievals.

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The MPL consists of four main components: 1) a computer, 2) a dedicated data acquisition and lidar control system, 3) a diode-pumped Nd-YLF laser system, and 4) a co-axial transceiver for transmitting the laser pulses and detecting the collected photons. Following is a description of each component:

1. **The Computer**: Currently, IBM laptops are used with all ARM MPL systems. A migration to an alternative small form factor PC is planned in 2004.

2. **Lidar Control System**: The lidar control system, custom produced by Science and Engineering Services Inc. (SESI), provides conditioned power to the photon detector and laser energy monitor. It contains an integrated A/D converter for reporting of vital system parameters to the instrument PC. It also contains the range-selectable multi-channel scalar which accumulates the range-resolved backscatter profiles.

   At present, all ARM MPL systems use this lidar control system by SESI, but a migration to lidar control system by ASRC is planned in 2004.

3. **Laser-Diode Pumped Nd-Ylf Laser System**: A rack-mount laser system provides CW laser diode infrared pump radiation via fiber optic to the Nd-YLF laser head within the transceiver. The rack-mount laser system also controls the pulse repetition rate of the Nd-YLF laser head incorporated into the MPL transceiver (described below). Originally, all MPL systems used Spectra Physics lasers (model 7300 or "R-Series"), but as these lasers were discontinued some MPL systems now use laser systems with similar specifications from other third party vendors.

4. **Co-Axial Transceiver**: The "transceiver" serves as both transmitter of the outgoing laser pulses and receiver of backscattered light. Approximately 1.0 watt of infrared CW pump radiation is converted to about 25 mW pulses of green laser light (523 nm) at 2500 Hz by the Nd-YLF laser head with non-linear optical frequency doubler. The pulses of green light are passed through a linear polarizing beam splitter, a depolarizing wedge, and expanded to fill an 8" Celestron telescope.

   The detection optics begins with the same 8" Celestron telescope. Returning photons incident on the telescope are collected and pass through the depolarizing wedge. About half of the collected photons pass through the polarizing beamsplitter cube and half are reflected. Light passing through the beamsplitter is collimated and passed through two narrow-band interference filters (0.27 nm fwhm) in order to reject most of the ambient light, and is ultimately focused onto a photon counting APD module from Perkin Elmer model SPCM-AQR-121-FC.

7.1.2 System Configuration and Measurement Methods

The MPL is configured to operate autonomously in an unattended manner 24 hours a day. Standard ARM deployments have the MPL oriented vertically (or slightly off vertical).

7.1.3 Specifications

Wavelength of laser pulse: 523.5 nm

Length of laser pulse: ~10 ns = 3 m

Range resolution (height interval): 30 m

Maximum range for cloud base height: 18 km

Typical averaging: 30 sec (60 seconds for some locations)

7.2 Theory of Operation

The principle is straightforward. A short pulse of laser light is transmitted from the telescope. As the pulse travels along, part of it is scattered by molecules, water droplets, or other objects in the atmosphere. The greater the number of scatterers, the greater the part scattered. A small portion of the scattered light is scattered back, collected by the telescope, and detected.

The detected signal is stored in bins according to how long it has been since the pulse was transmitted, which is directly related to how far away the backscatter occurred.

The collection of bins for each pulse is called a profile. A cloud would be evident as an increase or spike in the back-scattered signal profile, since the water droplets that make up the cloud will produce a lot of backscatter.

7.3 Calibration

7.3.1 Theory

Little calibration is necessary for cloud-base height determination. To fix the distance scale, it is necessary to use a calibrated-pulse generator capable of producing a trigger pulse and a second delayed pulse with an accurately known time lag. The two pulses are used to mimic a transmitted laser pulse and detected backscatter pulse with time delay relating to a simulated distance.

Absolute calibration of the magnitude of the lidar signal is much more difficult. The following instrument-level corrections are required:

1. “Dead-time” correction to account for detector non-linear response
2. Detector “afterpulse” subtraction
3. Background subtraction
4. Range-squared correction
5. Near-field detector overlap correction
6. Energy-monitor normalization.

Even after these various corrections are applied, the overall system transmittance is only coarsely known. Determination of this overall system calibration is typically obtained by comparison against other external measurements, modeled results, or both.

7.3.2 Procedures

This section is not applicable to this instrument.

7.3.3 History

As MPL systems are returned to PNNL for repair, timing calibration checks of the multichannel scalar are performed using HP precision pulse generators with sub-nanosecond accuracy. We have never yet found a multichannel scalar out of specification. Each of the calibrations described in the above section are applied by the MPLnor value-added product. The detector deadtime corrections are from vendor-supplied data sheets unique to each detector. Each of the other corrections is determined either through measurements conducted during installation, or from the real-time data.

7.4 Operation and Maintenance

7.4.1 User Manual

This section is not applicable to this instrument.

7.4.2 Routine and Corrective Maintenance Documentation

Little maintenance is required other than routine cleaning of the viewport window and gentle cleaning of dust from the telescope. Occasionally, the software or computer may lock up so visual confirmation that the program is operating, that the clock is updating, and that the displayed measurement agrees with reality are also required.

7.4.3 Software Documentation

This section is not applicable to this instrument.

7.4.4 Additional Documentation

Preventative Maintenance Procedure Summaries for the MPL at the Southern Great Plains (SGP) Site.

7.5 Glossary

See the ARM Glossary.

7.6 Acronyms

LIDAR: Light Detection and Ranging

Also see the ARM Acronyms and Abbreviations.

7.7 Citable References

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